MULTIPLEX HIERARCHY FOR HIGH CAPACITY TRANSPORT SYSTEMS

BACKGROUND OF THE INVENTION

Field of the Invention

This invention is concerned with very high capacity transport systems, and in particular with a method of providing a multiplex hierarchy for very high capacity transport systems.

Background art

The dominant signal format in the fiber optic networks follows the synchronous standard SONET in North America and SDH elsewhere. SONET/SDH enables multiplexing, adding/dropping, and general transportation of signals. SONET/SDH is a physical carrier technology, which can provide transport services for ATM, SMDS, frame relay, T1, E1, etc. As well, operation, administration, maintenance and provisioning (OAM&P) features of SONET/SDH provide the ability to reduce the amount of back-to-back multiplexing, and more importantly, network providers can reduce the operation cost of the network.

The SONET standard Bellcore GR-253-CORE and SDH standard ITU G.707 define the physical interface, optical line rates known as optical carrier signals, a frame format, and an OAM&P protocol. Opto/electrical conversion takes place at the periphery of the SONET/SDH network, where the optical signals are converted into a standard electrical format called the synchronous transport signal (STS) in SONET or synchronous transport module (STM) in SDH.

These standards define a basic rate, which is STS-1 for SONET and STM-1 for SDH. The rate of an STM-1 is three times higher than the rate of an STS-1. Lower and higher rate signals are defined from these basic rates. The lower rate signals are called VT (virtual tributaries) for SONET, and VC (virtual containers) for SDH. The higher rate signals are called STS-N and STM-N, respectively, where "N" takes in practice certain integer values. Examples of SONET STS-N signals are STS-3, STS-12,

STS-48, STS-198, etc. Examples of STM-N signals are STM-3, STM-4, STM 64, etc.

Frame structures with a very flexible granularity may be obtained by multiplexing lower rates tributaries in an appropriately sized frame, in a hierarchy that allows correctly delivering the signal to its owner. A tributary may have a phase offset with respect to the beginning of the frame, so that pointers are used to "point" to the first byte of information. The complexity of the frame hierarchical structure increases with the bit-rate, so that assembly and disassembly, as well as processing of the associated pointer information became more complicated. These operations must be performed separately for each signal, which means a large silicon area required with the inherent disadvantages.

For instance, in the case of a STM-1 frame with 64 VC-12 signals, each of the transmitting and receiving nodes must be equipped with common equipment that demultiplexes/multiplexes the VC's and processes the pointers, as well as with 64 independent channels, one for each VC. Each channel needs buffers, means for interpreting the pointers for aligning the incoming tributaries, means for generating the new pointers for the outgoing signals, etc. For same VC-12 granularity, the number of channels for a STM-64 increases to 64x64=4086.

United States Patent No. 5,666,351 (Oksanen et al.) issued on September 9, 1997 and assigned to Nokia Telecommunications Oy discloses a method for assembling and disassembling SDH frame structures with less hardware. At least two signals at the same hierarchy level are processed simultaneously, resulting in a time-division architecture. While the required silicon area is reduced with this architecture, the complexity of pointer processing is not. Also, this patent is not concerned with reducing the bandwidth occupied by the pointers during the transport of hierarchically multiplexed signals.

There remains a need for an efficient multiplexing hierarchy for high capacity transport networks, with a reduced pointer density, for simplifying

the operations necessary for pointer processing, and for reducing the bandwidth of the high speed signal.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an efficient multiplexing hierarchy for high capacity synchronous transport networks, that alleviates totally or in part the drawbacks of the existing multiplexing hierarchies.

Another object of the invention is to provide a novel multiplexing hierarchy that uses nested pointers, whereby the high rate spans of a transport network do not see the STS-1/STM-1 pointer granularity.

Still another object of the present invention is to extend the SONET/SDH multiplexing hierarchy to higher rates by creating a new virtual container of a higher capacity, and its associate pointer.

According to one aspect of the invention, there is provided a method of assembly a frame structure of a SDH signal at a hierarchy level N, comprising, receiving a hierarchically multiplexed administrative unit AU-n comprising a payload and an AU-n pointer, converting said AU-n to a tributary unit TU-n, and hierarchically multiplexing said TU-n into said frame structure, where n≥3, and gives the granularity of said SDH signal, and said AU-n pointer provides the beginning of said payload with respect to said frame.

According to a further aspect of the invention, there is provided a method of assembling a frame structure of a SDH signal comprising, receiving a hierarchically multiplexed administrative unit AU-n-mc comprising a concatenated payload and an AU-n-mc pointer, converting said AU-n-mc to a tributary unit TU-n-mc, and hierarchically multiplexing said TU-n-mc into said frame structure, where n≥3, and gives the granularity of said payload, m is he level of concatenation and said AU-n pointer provides the beginning of said payload with respect to said frame.

According to yet a further aspect of the invention, there is further provided a method of reducing the number of AU pointers of a very high

speed synchronous transport signal STM-N with AU-n granularity,an AU-n unit having an AU pointer and an AU payload, the method comprising, for each AU-n unit, hiding said AU-n pointer into said AU payload, translating said AU-n payload to a TU-n payload, and hierarchically multiplexing said TU-n into said frame structure.

The invention is further directed to a hierarchically multiplexed signal for transport over a multiplex section of a synchronous network, comprising-a payload field with a coarse AU granularity corresponding to the granularity of a higher order tributary, said payload field carrying a plurality of fine granularity AU pointers hidden in a TU pointer area, and-a section overhead field including a coarse granularity AU pointer.

The novel hierarchy uses preferably a single pointer at the STM-4/STS-12 level and a path overhead with a minimum granularity of an STS-12 / STM-4 SPE. Of course, higher minimum granularities for the pointers and the POH can also be selected for even faster rates.

The tributary interfaces described are SDH/SONET in nature. Nonetheless, the novel multiplexing hierarchy may support other interfaces, such as 1G Ethernet.

An advantage of the multiplexing hierarchy according to the invention is a reduced number of pointers on the high capacity line. Fewer pointers results in reducing the current complexity of pointer processing.

Another advantage of the multiplex hierarchy according to the invention is scalability, i.e. the hierarchy may be extended to higher rates, as needed.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiments, as illustrated in the appended drawings, where:

Figure 1A shows an STM-N frame;

Figure 1B shows the current multiplexing hierarchy as detailed in G.707;

Figure 2 shows a block diagram of the multiplexing hierarchy according to an embodiment of the invention, for a VC-5 granularity;

Figure 3 illustrates creation of a STM frame directly from AU-3's using TU pointer transformation;

Figure 4 shows how an AU-3 is translated to a TU-3;

Figure 5 shows the translation of an AU-3-3c or an AU-4 to a TU-4;

Figure 6 illustrates the translation of an AU-3-12c, an AU-4-4c, an AU-3-12 or an AU4-4 to a TU-5;

Figure 7 shows the translation of an AU-3-48c or an AU-4-16c to a TU-5-4c;

Figure 8 illustrates the translation of an AU-3-192c or an AU4-64c to an TU-5-16c;

Figure 9 shows the translation of an AU-3-768c or an AU-4-256c to a TU-5-64c;

Figure 10 shows mapping of a TUG-3 into a VC-4;

Figure 11 shows aligning of a VC-4 into a TU-4;

Figure 12 shows multiplexing of TUG-4's into a TUG-5;

Figure 13 shows mapping of a TUG-5 into a VC-5;

Figure 14 illustrates mapping of a C-5 into a VC-5;

Figure 15 illustrates the mapping of a C-5-nc into a VC-5-nc;

Figure 16 illustrates mapping of a TUG-5-nc into a VC-5-nc;

Figure 17 shows concatenation of a VC-5-nc;

Figure 15 illustrates the mapping of a C-5-nc into a VC-5-nc;

Figure 18 illustrates the frame structure for byte interleaved at AU-3 or AU-4;

Figure 19 illustrates the frame structure for the 40GBps with higher order containers;

Figure 20 is a block diagram of showing how the multiplex hierarchy can be extended for a VC-6 granularity; and

Figure 21 is a block diagram of how the multiplex hierarchy can be applied to non-SDH/SONET formats.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The multiplex hierarchy is described in connection with the SDH standard, but it is to be understood that the invention is equally applicable to SONET signals or to non-SONET/SDH signals. The conventions and terminology used in this document are in line with G.707.

Some of the terms used in this specification are defined next in connection with Figures 1A and 1B. Figure 1A shows an STM-N frame **1** and Figure 1B shows the current multiplexing hierarchy as detailed in G.707, for generating frame **1** with containers of various sizes. The double-line boxes on Figure 1B indicate a pointer processing operation, and a course dotted line coming into such boxes indicates an aligning operation. The pointer processing and the corresponding alignment of the payload are performed at the TU-n and AU-n level. The thicker solid lines indicate a multiplexing operation, and the thinner solid lines indicate a mapping operation. Same representations are maintained throughout the drawings.

<u>Synchronous Transport Module (STM)</u>

A STM is the information structure used to support section layer connections in an SDH network. The information is organized in a block frame structure which repeats every 125 microseconds. The information is suitably conditioned for serial transmission on the selected media at a rate, which is synchronized to the network. A basic STM is defined at 155,520 Kbit/s. This is termed STM-1 and is analogous to the GR.253 SONET STS-3.

Figure 1A illustrates an STM-N frame **1** organized in 9 rows and 270xN columns, where N gives the rate of the respective STM-N. Frame **1** comprises an information payload field **39**, which takes 261xN columns, and an overhead field **3, 3'**, which takes 9xN columns.

An overhead field is necessarily added in the STM frame for OAM&P purposes, such as fault and performance monitoring, start of frame, start of

payload, etc. The overhead comprises OAM&P information field **3** for the regenerator section layer, and field **3'** for multiplex section layer.

The regenerator section (section in SONET terminology) layer deals with the transport of multiplexed signals across a physical medium. A regenerator section is a portion of the transmission facility between two regenerators, add-drop multiplexers (ADM) or terminals. Functions include framing, scrambling, section error monitoring and an embedded communication channel.

The multiplex section (line in SONET terminology) layer provides synchronization and multiplexing for the path layer. A multiplex section is a portion of the transmission facility between two consecutive add-drop multiplexers or terminals (TM).

The path layer deals with the transport of services, such as CEPT-1, between ADMs, terminals serving routers, bridges, PBXs or switches. A path overhead (POH) is necessarily added for monitoring the tributaries. The main function of the path layer is to map the services and POH into STM-1s. The higher multiplexing level for POH is currently at the STM-1 level, and the lower multiplexing level is at the VC-11 level.

STM-N information payload field **39** comprises path overhead information for each tributary carried in the field 39, an effective payload field **44**, and columns with fixed stuff necessary for maintaining the synchronous rate at the respective hierarchical level. This field may have various granularities, allowing a large degree of flexibility for the rates of the tributaries that form the high rate signal. The current and new multiplexing hierarchies are described next for various granularities of the payload field **39**.

Throughout the specification, the information payload field (or the payload) is referred to with reference numeral **39**, the effective information with **44**, the stuff bytes with **24**, and the POH bytes with **14**.

<u>Container-*n* (C-*n*)</u>:

A container is the information structure which forms the synchronous information payload.

Adaptation functions have been defined for many common network rates into a limited number of standard containers, namely Container-1 (C-11, C-12), Container-2 (C-2), Container-3 (C-3) and Container-4 (C-4). These containers are defined in G.707, and are used currently in the synchronous networks as the basic information unit to be multiplexed into an STM frame. These G.707 containers are denoted with **4** throughout the specification, irrespective of their size, for simplification.

Some services that operate at a higher rate may be transmitted in a concatenated signal. Concatenation is a procedure by which tributaries having same source and destination are adapted into a larger container sizes as a multiple integer of one of the above containers with a single POH, and travel together along the same path. For example, services that may fit into sixteen C-4 containers may be mapped into a C-4-**16c** container, which is 16 times larger than a C-4. G.707 defies concatenations of C-4.

This specification defines, in addition to the G.707 containers, higher order containers C-n, where n≥5. C-5 is selected of a size corresponding to an STM-4 or a SONET STS-12, and is shown in Figure 2 at **10**. Concatenations of C-5 at the 4, 16 and 64 level are also defined herein, shown in Figure 2 at **11**, **12** and respectively **13**.

The capacity of the containers currently in use and of the containers newly defined in this specification is detailed in Table 1. The new containers and their sizes are indicated in bold. Larger containers such as C-6, C-7, C-8, etc., not shown in Table 1, are also the object of this invention, the respective rates being determined by extrapolation.

Table 1: Payloads for higher order containers.

New containers		G.707 Container–n	
Container – n (C-*n*)	Payload (MBps)	(C-*n*)	Payload (MBps)
C-3	48.384	C-3	48.384
C-4	149.760	C-4	149.760
C-5	**603.648**	C-4-4c (4xC-4)	599.040
C-5-4c (4xC-5)	**2,414.592**	C-4-16c (16xC-4)	2,396.160
C-5-16c(16xC-5)	**9,658.368**	C-4-64c (64xC-4)	9,584.640
C-5-64c(64xC-5)	**38,633.472**	C-4-256c (256xC-5)	38,338.560

It is to be noted that the payload for the newly defined containers is slightly larger than that of the corresponding G.707 container. This is due to the extra columns allocated for nesting pointers in an AU-*n* to TU-*n* translation, as it will be described later.

<u>Virtual Container-*n* (VC-*n*)</u>:

For each of the defined containers, there is a corresponding virtual container (VC). A virtual container is the information structure used to support path layer connections in the SDH. It comprises the effective information payload **44** in a respective container and the POH information pertinent to the path between the end users of the respective payload information. Alignment information to identify the VC-n frame start is provided by the server network layer.

G.707 describes virtual containers up to a VC-4, as shown in Figure 1B. Existing VC's are classified into lower order virtual containers VC-11, VC-12, VC-2 and VC-3, denoted herein with **5**, and higher order virtual containers VC-3 and VC-4, denoted herein with **8**. A higher order VC can carry payloads of lower order VC's multiplexed together, each having its own POH. For example a VC-3 could be made of 28xVC-11, 21xVC-12, 14xVC-1, 7xVC-2 or 1xVC-3. A VC-4 could be made of 3xVC-3, or a VC-4, etc.

This specification defines in addition to the virtual containers **5** and **8**, higher order VC-n's, where n≥5, corresponding to new containers C-n. The new VC-5 has a payload equivalent to an STM-4/STS-12 SPE. Thus, a VC-5 comprises the information in a C-5 and the POH corresponding to that level.

Concatenations of VC-5 at the 4, 16 and 64 level are also defined herein.

<u>Tributary Unit-n (TU-n)</u>:

A tributary unit TU is an information structure which provides adaptation between the lower and higher order paths. It comprises an information payload of a correspondingly sized order virtual container, and a tributary unit pointer (TU pointer), for VC-n alignment. VC-n alignment is a procedure by which the VC offset information is incorporated into a TU frame, to adapt the payload frame start relative to the higher order virtual container frame start. The pointers are located in the first column(s) of the TU.

As shown in Figure 1B by reference numeral **6**, G.707 describes tributary units up to TU-3. The lower visible TU pointer granularity in the current synchronous networks is at the TU-11 level.

The present invention extends the concept of the tributary units TU-n for n = 4, namely TU-4 shown in Figure 2 at **20** and for n = 5, namely TU-5 **25**. Also, concatenations at the TU-4 level are provided for, such as units shown at **21**, **22** and **23** on Figure 2. Of course, the invention is applicable also to higher values for n (i.e. to higher rates).

<u>Tributary Unit Groups-n (TUG-n)</u>

One or more tributary units **6**, can be multiplexed and mapped into fixed, defined positions in a higher order VC-*n* payload, forming a tributary unit group (TUG) **7**. TU multiplexing is a procedure by which multiple lower order path signals are adapted into a higher order path. The multiplexing operation is shown in the drawings in thick solid lines, with a nearby multiplexing factor.

TUG's are defined in such a way that mixed capacity payloads made up of different size tributary units can be constructed to increase flexibility of the transport network.

For example, Figure 1B shows that a TUG-2 may comprise a homogeneous assembly of identical TU-1s (i.e. 4 TU-11's or 3 TU-12's), or a TU-2. A TUG-3 may comprise a homogeneous assembly of lower order TUG's (i.e. seven TUG-2's), or a TU-3.

A higher order virtual container (n = 3, 4) shown by reference numeral **8** on Figure 1B, may comprise either a single higher order container, or an assembly of tributary unit groups **7** (TUG-2's, TUG-3's), together with a POH appropriate to that level. For example, a VC-4 can carry a container C-4, or 3x TUG-3's multiplexed together, while a VC-3 can carry a C-3 or 7xTUG-2's. TUG's are defined in such a way that mixed capacity payloads made up of different size tributary units can be constructed to increase flexibility of the transport network.

The present invention defines new groups TUG-4 and TUG-5, denoted with **30** and respectively **35**. A TUG-4 may comprise a homogeneous assembly of TUG-3s or a TU-4, and a TUG-5 may include a homogeneous assembly of TUG-4s or a TU-5. Concatenations at the TUG-4 level are also new, and they are shown at **31**, **32** and **33** in Figure 2. The invention is also applicable to higher order TUG's.

<u>Administrative Unit-n (AU-n)</u>:

An administrative unit AU, shown at **9** in Figure 1B, is the information structure which provides adaptation between the higher order path layer and the multiplex section layer. It is obtained by mapping a higher order virtual container into the payload **39**, and adding an administrative unit pointer, shown at **2** in Figure 1A. The AU pointer location is fixed with respect to the STM frame and is located in the regenerator section overhead field **3**.

AU pointers indicate the offset of the payload frame start relative to the multiplex section frame start.

G.707 currently describes administrative units AU-4 and AU-3; an AU-n is equivalent to the SONET STS, an AU-3 is equivalent to a SONET STS-1, and an AU-4 is equivalent to an STS-3c.

An STM-N described in G.707 comprises Nx3 AU-3's, or NxAU-4's.

A new administrative unit AU-5 is introduced for the new multiplexing hierarchy descried herein, as illustrated at **55** on Figure 2. The AU-5 comprises a VC-5 and an administrative unit pointer, which indicates the phase alignment of the VC-5 with respect to the STM-N frame. As in the case of the current hierarchy, the AU-5 pointer location is fixed with respect to the STM-N frame. Larger AU-n's, such as concatenations of the AU-5's are also the object of the invention.

The STM-N described in this document may comprise Nx3 AU-3's, NxAU-4's or N/4 AU-5s, which are byte interleaved together.

<u>Administrative unit Group (AUG)</u>

AU multiplexing is a procedure by which multiple higher order path layer signals are adapted into a multiplex section. As for the TU multiplexing, this operation is shown in the drawings in thick solid lines, with a nearby multiplexing factor.

One or more administrative units occupying fixed, defined positions in an STM payload form an administrative unit group (AUG). An AUG **1'** consists of a homogeneous assembly of AU-3's, or AU-4's.

With the current multiplexing hierarchy shown in Figure 1B, if the tributaries are STM-1/ STS-3's, a 40GBps signal (an STM-256) needs 256 pointers (AU-4 pointers) on the multiplex section (line) for AU multiplexing. It is apparent that if the STM-256 is obtained by hierarchically multiplexing AU-3s, (analogous to the SONET STS-1 multiplex hierarchy) the number of AU-3 pointers on the multiplex line becomes 768, since the payload field comprises 786 AUG-3's. Clearly, a straightforward extrapolation of the existing multiplexing pattern will create increasingly higher STS pointer density as the rate of the network grows. It is also evident that for very high capacity transport systems, granularity of this order is not required and indeed adds significant complexity to any product.

With the newly introduced AU-5, an AUG-4 illustrated at **15** on Figure 2, may be made of an AU-5. In addition, higher order AUG's, such as AUG-16, AUG-64 and AUG-256 are shown at **16**, **17** and **18**.

Figure 2 shows the relationship between various multiplexing elements with the new containers and the novel multiplexing hierarchy, for obtaining an STM-256 (STS-786) with VC-5 granularity. The lines marked with letters on Figure 2 show operations that are not provided for by G.707, and which are described in more details in Figures 4-17.

TU pointer transformation is a procedure introduced by this invention, whereby the AU pointer is adapted to become a TU pointer, i.e. the AU pointer is removed from the SOH and placed in the payload. Nesting of pointers according to the novel hierarchy implies, in the example of Figure 2, translation of AU-3's and AU-4's into the new tributary units TU-4 and TU-5. It is however to be understood that the invention is applicable for other rates. TU pointer transformation and TU pointer transformation according to the present invention are illustrated by the fine dotted lines denoted with **a-f**.

For lower order containers, the multiplexing hierarchy is similar to that shown in Figure 1B. For example, a C-3 container **4** is mapped into a VC-3 container **5** in the known way. In addition to the G.707 hierarchy, the TU-3 unit **6** may be now obtained also from an AU-3, using TU pointer transformation illustrated by line **a**. Namely, the AU-3 pointers are extracted from the SOH field and mapped into the payload field, as it will be explained in more details in connection with Figure 4.

A TU-3 unit **6** is mapped into a TUG-3 group **7**. A higher order VC-4 container **8** is obtained either by multiplexing three TUG-3 groups **7**, shown by line **g** and detailed in Figure 10, or directly from a C-4 container **4**. The resulting VC-4 container **8** is now being aligned into the new TU-4 unit **20**, using a TU pointer, rather than being aligned into an AU-4 using an AU pointer, as in G.707. This is shown by dotted line **h** on Figure 2, and illustrated in more detail in Figure 11.

The new TU-4 unit **20** may also be comprised of an AU-3-3c or an AU-4, as shown by dotted line **b**. In this case, the AU pointers in the AU's are transformed into TU pointers, as illustrated in Figure 5.

TU pointer transformation is also necessary for generating the new TU-5 unit **25**, if formed with administrative units. A TU-5 may comprise an AU-2-12c, an AU-4-4c, an AU-3-12 to AU-3-738 or an AU-4-4 to AU-4-256, as shown by line **c** and illustrated in detail on Figure 6.

Figure 2 also shows TU pointer transformation for generating the new concatenated tributary units, such as TU-5-4c unit **21**, TU-5-16c unit **22** and TU-5-64c unit **23**. A TU-5-4c unit **21** may be formed from an AU-3-48 or an AU-4-16c, using TU pointer transformation shown by line **d**, and illustrated in more details in Figure 7. A TU-5-16c unit **22** may be formed from an AU-3-192 or an AU-4-64c, using TU pointer transformation shown by line **e**, and further shown in more details in Figure 8. Finally, a TU-5-16c unit **23** may be formed from an AU-3-786 or an AU-4-256c, using TU pointer transformation shown by line **f**, and further shown in more details on Figure 9.

~~The translation from AU-n to their corresponding AU-n is shown in Table 2, which complements Figure 2. The information content and pointers of both structures are identical, it is only the position of pointers with respect to the payload that changes during translation. Table 2 also shows how the very high rate network transports synchronous traffic created using byte interleaved AU-3s and AU-4s, by hiding the pointers from the line through nesting pointers. The last column indicates where a translation operation takes place in Figure 2, and indicates the Figures where the respective operation is illustrated in more details.~~

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Table 2 Relationship between Synchronous Module, AU-*n* and TU-*n*

Tributary Interface		Section OH Termination of tributaries	Au-TU Pointer Translation	Shown on Figure 2
SDH	**SONET**	**AU-n**	**TU-n**	
STM-0	STS-1	AU-3	TU-3	a (Fig. 4)
	STS-3c	AU-3-3c	TU-4	b (Fig. 5)
	STS-12c	AU-3-12c	TU-5	c (Fig. 6)
	STS-48c	AU-3-48c	TU-5-4c	d (Fig. 7)
	STS-192c	AU-3-192c	TU-5-16c	e (Fig. 8)
	STS-768c	AU-3-768c	TU-5-64c	f (Fig. 9)
STM-1		AU-4	TU-4	b
STM-4-4c		AU-4-4c	TU-5	c
STM16-16c		AU-4-16c	TU-5-4c	d
STM-64-64c		AU-4-64c	TU-5-16c	e
STM-256-256c		AU-4-256c	TU-5-64c	f
	STS-3	AU-3-3	TU-4	b
	STS-12	AU-3-12	TU-5	c
	STS-48	AU-3-48	TU-5-4	c
	STS-192	AU-3-192	TU-5-16	c
	STS-768	AU-3-768	TU-5-64	c
STM-4		AU-4-4	TU-5	c
STM-16		AU-4-16	TU-5-4	c
STM-64		AU-4-64	TU-5-16	c
STM-256		AU-4-256	TU-5-64	c

All the tributary interfaces in the table are actual SDH/SONET and are therefore mapped into an AU-3-nc or AU-4-nc format. The new administrative group AU-5 is not shown in Table 2 since it is assigned only to VC-5s or TUG-5s. These clients will be mapped into TU-5-mc's which will in turn be mapped into VC-5s and an AU-5 pointer will then be added.

The first row in Table 2 shows "hiding" of the tributary pointers necessary for translating AU-3's to TU-3's. All other tributary units listed in Table 2 refer to the new containers, i.e. TU-4 and TU-5.

The new tributary unit groups TUG-4 and TUG-5 denoted with **30** and **35** respectively, are obtained by mapping a respective tributary unit TU-4 and TU-5. A TUG-5 group **35** may alternatively be obtained by multiplexing four TUG-4's, as indicated by line **i** and detailed in Figure 12.

A TUG-5-nc is mapped into an adequate VC-5-nc by adding the POH appropriate for that level, as shown by line **k** and detailed in Figure 16. The VC-5-nc container is then aligned into the respective AU-5-nc unit, and a respective STM-N is generated as indicated above.

A TUG-5 or a C-5 may be mapped into the new VC-5container **45**, as shown by the thin solid lines **j** and **m**, and detailed in Figures 13 and 14. Larger containers, such as C-6 (or C-5-4c), C-7 (or C-5-16c), and C-8 (or C-5-64c), map into a VC-5-nc, by adding the path overhead, as shown by example with line **n** and detailed in Figure 15.

Due to concatenation, VC-5-nc's **41**, **42**, and **43** have (n-1) less columns than if they were generated from the corresponding lower order containers. To maintain the AU-5 frame size, N-1 columns of fixed stuff need to be added, as shown in Figure 17. For example, for a C-5-4c there will be one column of path overhead and three, (n-1, where n=4), columns of fixed stuff mapped into a VC-5-4c. Although it may seem advantageous to remove these additional columns of fixed stuff for the C-5-4c mapping and assign them as payload, the fixed stuff columns are not removed in the interests of scalability. This is because as the hierarchy scales and a VC-6 and AU-6 are created, the TUG-6 (TUG-5-4c, in this hierarchy) will normally map into a VC-6 instead of a VC-5-4c. This TUG-6 to VC-6 mapping will add a column of path overhead, but no fixed stuff. If the C-5-4c container were increased to use the columns of fixed stuff for the AU-5 hierarchy, it would be too large to map into a VC-6 for an AU-6 hierarchy.

The AU-5 unit **55** comprises a VC-5 **45** and the respective administrative unit pointer, which indicates the phase alignment of the VC-

5 with respect to the STM-N frame. With the newly introduced AU-5 unit **55**, an AUG-4 group **15**, made currently of four AU-4's or twelve (4x3) AU-3's according to G.707, may also be made of an AU-5 unit **55**, as shown in Figure 2.

Figure 3 shows an example of how an STM-N is made starting with AU-3 units **9** and using the new VC-5 container **45**, as illustrated also by the hierarchy depicted along the path illustrated in Figure 2, from fine dotted arrow **a** showing AU-3 translation, to AUG-4 group **15**.

In the first step **s1**, the AU-3 unit **9** is shown as comprising a VC-3 and the respective AU-3 pointers **34**. Next, in step **s2** the AU-3 is translated into a TU-3 unit **6** by transforming the AU-pointers **34** into TU-3 pointers **29**. The TU-3 unit **6** is mapped into a TUG-3 group **7** in step **s3**, and three TUG-3's are multiplexed into a VC-4 container **8**, shown in step **s4**. At this point, the POH **14** is added at the VC-4 level. The VC-4 is aligned into the new TU-4 unit **20** using the respective TU-pointers **29**, shown in step **s5**, and the TU-4 is mapped into a TUG-4 group **30,** shown in step **s6**.

On the next multiplexing level, four TUG-4's are multiplexed into a TUG-5 group **35** in step **s7**, and a container VC-5 **45** is formed by adding the POH for this level, step **s8**. The VC-5 is aligned into the new AU-5 unit **55**, by generating the AU pointers, **s9**, and the AU-5 is mapped into an adequate sized administrative unit group AUG-4 group **15**, as shown in step **s10**. Finally, the STM-N is generated by multiplexing N/4 AUG-4 groups **15**, and adding the section overhead.

<u>Translation of AU-n to TU-n</u>

Figure 4 shows how an AU-3 (which has the rate of a SONET STS-1) is translated into a TU-3, (line **a** in Figure 2). An AU-3 comprises an 87-columns by 9-rows field **39**, and the AU pointer **34**. The AU pointer includes bytes H1, H2 and H3 that give the beginning of field **39** into the frame. Field **39** includes the payload **44,** a 9-byte POH **14**, and fixed stuff columns **24**.

A TU-3 consists of a 9 row by 86 columns field, including payload **44** (a VC-3), POH **14**, and a TU-3 pointer **29**. The TU –3 pointer, which

includes bytes H1, H2, H3, gives the phase of the VC-3 within the TU-3. The TU pointer is located in the first column of the TU-3, the rest of the first column being allocated to fixed stuff **24**.

The translation from AU-3 to TU-3 relies on removing the columns of fixed stuff **24** within the AU-3 payload, and mapping the AU pointers **34** into the first column of the TU-3.

Figure 5 shows a translation from AU-4 or AU-3-3c to TU-4. Field **39** of AU-4 unit **9** includes 261 columns by 9 rows, with the 9-byte POH **14**, which can carry a VC-4 or an STS-3c, and also comprises a 9-byte AU pointer field **34**.

Figure 5 also shows the size and structure of the new TU-4 unit **20**. A TU-4 consists of 9 rows by 262 columns to carry a VC-4. The phase of the VC-4 with respect to the TU-4 is indicated by the TU-4 pointer **29** in the first column, comprising the three times bytes H1, H2 and H3. A TU-4 also has a 9-byte POH **14**. The translation relies on allocating the first column of the TU-4 to the AU pointer **34**, which becomes the TU pointer **29**. As seen from Table 2, an AU-3-3 can also be translated to a TU-4 in a similar way.

Figure 6 shows a translation from an AU-3-12 (AU-3-12c) or an AU-4-4 (AU-4-4c) signal into a TU-5. G.707 requires that AU-3-12 (AU-3-12c) or AU-4-4 (AU-4-4c) be demultiplexed to the STM-1 level and byte interleaved as AU-4s. Using the multiplexing hierarchy according to the invention, it is now only necessary to demultiplex these signals to AU-5 granularity.

Field **39** of an AU-3-12 or an AU-4-4 comprises 1044 columns, with 3 columns of fixed stuff **24**, a one-column POH **14** and the respective effective payload field **44**. For the lowest granularity at this level, the AU pointers **36** occupy 36 (12x3) bytes. As such, a 4-column field is needed for accommodating the 36 bytes of the AU pointers **34** when the AU is translated into TU.

As such, the new TU-5 unit **25** has the first four columns (4x9=36 bytes) allocated to TU pointers **29**. The TU-5 pointer has twelve H1, H2 and H3 bytes, which indicate the phase of the VC-5 with respect to the TU-5.

The TU-5 unit **25** also comprises 1048 columns, for accommodating a VC-5, POH **14** and three columns of fixed stuff **24**.

AU-3-n's and AU-4-n's with n>12 (n=48, 192, 256, 738, can be translated into TU-5's in a similar way.

Figure 7 shows a translation from an AU-3-48c or an AU-4-16c signal into a TU-5-4c, line **d** in Figure 2), with respective TU pointer transformation. Field **39** of an AU-3-48c has 4176 columns by 9 rows, with POH **14** and 15 columns of fixed stuff **24**. The AU pointers **34** of the AU-3-48c occupy 144 bytes, which can be mapped to 16 columns (144:9=16). For transformation, the 16-column AU pointers are placed in the first four columns of each of the four TU-5's of the TU-5-4c, to give the phase of the VC-5-4c with respect to the TU-5. The POH **14** is placed in the 5th column of the first TU-5.

Figure 8 shows a translation from an AU-3-192c or an AU-4-64c signal into a TU-5-16c. Field **39** of this AU is 16704 columns by 9 rows (the size of 16 TU-5's), with a POH **14**, 63 columns of fixed stuff **24** and a payload field **44**. The size of the AU pointers **34** is 576, which requires 64 columns (576 bytes :9 rows = 64 columns = 4x16). Similarly with the TU pointer transformation described in connection with Figure 7, the first 4 columns of all 16 TU-5's are allocated to the TU pointers **29**, and the single POH **14** is placed in the first TU-5 after the pointers **29**. The phase of the VC-5-16c with respect to the TU-5-16c in indicated by the TU-5-16c pointer.

Figure 9 shows a translation from an AU-3-768c or an AU-4-256c signal into a TU-5-64c (line **f** in Figure 2). Field **39** is 9 rows by 66816 columns (the size of 64 TU-5's), with POH **14** and 63 columns of fixed stuff **24**. The size of the AU pointer **34** in this case is 2304, which requires 256 columns (2304 bytes :9 rows = 256 = 4x64 columns). The first four columns of the 9-row by 1048-column TU-5's are allocated to the TU-5 pointer **29**, which now comprises the information in the AU pointer. The phase of the VC-5-64c with respect to the TU-5-64c in indicated by the TU-5-64c pointer.

<u>New mapping, multiplexing and aligning operations</u>

The arrangement of three TUG-3's multiplexed into a VC-4, line **g** in Figure 2, is shown in Figure 10. A TUG-3 group **7** is a 9-row by 86-column structure, with a TU pointer (H1, H2 and H3) in the first 3 rows of the first column, and a one-column POH **14**. A VC-4 consists of one column **14** of VC-4 POH, two columns of fixed stuff **24** and a 258 column effective payload structure **44**. The three TUG-3s are single byte interleaved into the 9-row by 258-column VC-4 payload structure and have a fixed phase with respect to the VC-4. The TU pointers are "hidden" into payload field **44**.

The aligning of a VC-4 container **8** into a TU-4 unit **20** (line **h** on Figure 2) is shown in Figure 11. As indicated in connection with Figure 5, a TU-4 consists of a VC-4 and a one-column TU-4 pointer **29**, comprising three times bytes H1, H2 and H3. The phase of the VC-4 with respect to the TU-4 is indicated by the TU-4 pointer **29**.

The preferred granularity for the novel multiplexing hierarchy is at VC-5 level. Therefore, the TUG-4 groups **30** are multiplexed into a TUG-5 group **35** as shown in Figure 12 (line **i** on Figure 2). A TUG-4 is a 9 rows by 262 columns structure, while a TUG-5 is a 9-row by 1048-column structure, so that four single byte interleaved TUG-4's form a TUG-5.

The mapping of a TUG-5 group **35** into a VC-5 container **45** is shown by line **j** on Figure 2 and in more details in Figure 13. Figure 13 also shows the size and structure of the new VC-5 container **45**. A VC-5 consists of one column of VC-5 POH **14** and a 1048 column payload structure, which is the size of TUG-5.

The mapping of a C-5 container **10** into a VC-5 container **45** is shown in Figure 14. The C-5 is a 9-row by 1048-column structure. The VC-5 consists of one column **14** of VC-5 POH and a 1048 column payload structure **44**.

<u>Concatenation and numbering schemes</u>

G.707 defines concatenated payloads at the VC-4 level. As a larger AU pointer and virtual container have been defined, it is now possible to perform concatenation at the VC-5 level.

The mapping of a C-5-*nc* container **21**, **22** or **23** into a VC-5-*nc* is shown by line n in Figure 2 and is illustrated in more details in Figure 15. The C-5-nc is a 9-row by 1048xn-column structure. The VC-5 consists of one column of VC-5 POH **14**, n-1 columns of fixed stuff and a 1048xn column payload structure **44**.

Figure 16 shows the mapping from TUG-5-nc's into VC-nc's, where n defines the level of concatenation and can be for example 4, 16, 64, or higher. In this case, the first TUG-5 receives the POH **14** for the VC-5-nc, while the remaining (n-1) TUG-5's have a fixed stuff first column.

Concatenated tributary units are a new concept from G.707. Figure 17 shows the frame size for a concatenated VC-5. To indicate the concatenated nature of the payload, a concatenation indicator **29** is assigned in the VC-5 path overhead **14**. This is required to prevent misconnection of the concatenated VC-5 payload.

As shown in Figure 1A, an STM-1 frame has 270 columns, the first nine containing the SOH and the remaining 261 columns containing the data payload. A numbering scheme is required to locate the TUG-n's within the very high speed network. G.707 defines a three-figure address (K, L, M) for the existing hierarchy. In the case of an AU-4 structured frame, K represents the TUG-3 number, L represents the TUG-2 number and M the TU-1 number. In the case of an AU-3 structured frame, only L and M are used.

This can logically be extended to include the new groups TUG-4 and TUG-5.

Table 3 TUG-*n* Numbering Scheme

TUG-*n*	Address	Range of values
TUG-5	I	1,2,3,4
TUG-4	J	1,2,3,4
TUG-3	K	1,2,3

A numbering scheme is also required to locate the AU-5s within the network. G.707 defines a two figure address (A, B) where A represents the AU-3 number and B the AU-4 number. This can logically be extended to include the AU-5.

Table 4 AU-*n* Numbering Scheme

AU-*n*	Address	Range of values
AU-5	C	1,2,3,4
AU-4	B	1,2,3,4
AU-3	A	1,2,3

<u>Frame Structure of the STM-N</u>

Figure 18 shows an STM-256 **1** with AU-3 granularity. The frame is 9 rows by 69120 columns (270x256), out of which 2304 columns (9x256) are used for the section overhead SOH, and 66816 for payload. Field **39** carries 786 AU-3's, it can also carry 256 AU-4's. It is apparent that the size of the AU pointers is 2304 bytes (256x9), shown by field **2** in Figure 18.

The STM-256/STS-768 frame structure **100** for the novel multiplexing hierarchy is shown Figure 19, with a similar AU-3/AU-4 granularity. The payload field **39** has now 67136 columns, being 320 columns larger than that of frame **1**. This is due to the bytes occupied by the nested pointers. As the payload is larger than for the current STM-N's, it is necessary to reduce the byte allocation for the SOH **3, 3'** to maintain a line rate in even multiples of the existing SONET/SDH line rates.

As shown in Figure 3, a STM-256 has now an AU-5 pointer that occupies a minimum of 64x3=192 bytes rather than 2304 bytes in frame **1** of Figure 19.

This approach has assumed scaling the G.707 frame with 3 bytes assigned for each AU-5 pointer (1 byte for H1, H2 and H3).

The AU-5 pointer according to the novel multiplexing hierarchy may be optimized for system performance. Namely, while H1 and H2 may still be one-byte pointers, H3 may vary from one to twelve bytes allowing for a larger negative justification area.

There are a number of possible methods for constructing the frame for this novel multiplex hierarchy:

- Maintain the line rate by keeping the frame size equivalent to a STM-256 frame consisting of AU-3s or AU-4s. This is achieved by reducing the number of columns for section and line overhead by 320. These reclaimed columns consisted of unused bytes.
- Reduce the frame size to the minimum required to contain the pointers and the defined overhead bytes.
- Embed the FEC and overhead within the frame.

The multiplex hierarchy in this invention is designed to be scalable to higher order virtual containers. Figure 20 shows how this multiplex hierarchy may be extended for a VC-6 and its associated AU-6. The same principles as defined here can be applied to further scale the granularity of the hierarchy as the network demands increase.

The STM-4 frame comprises now an AUG-16 group **16**, made of an AU-6, with the respective AU-6 pointer. The multiplexing hierarchy for containers C-6 is not show, and the hierarchy for C-4 and C-5 containers is similar to that illustrated in Figure 2, using similar TU pointer transformations and AU to TU translations. As the hierarchy progresses to higher rates, a C-6 container **60** is directly mapped into a new VC-6 container **46**. The VC-6 container **46** may also be made by translating AU-3-48c/AU-4/16c units to VC-6 granularity. Namely, these units are translated to a TU-6 unit **26** by transforming the AU-2 and AU-4 pointers into TU-6 pointers as shown by the fine dotted line. The TU-6 unit **26** is then mapped into a new TU-6 group 36, which is mapped into the VC-6 container **46**. Similarly, TU-6-4c's are obtained by TU pointer transformation and Au to TU translation from AU-3-192c's or AU-4-64c's, and TU-6-16c's are obtained from AU-3-786c's or AU-4-256c's.

New concatenated TUG-6's are also provided, namely TUG-6-4c and TUG-6-16c. As detailed for AU-5 hierarchy, the AU-6 hierarchy can scale by multiplexing AUG-16 groups **16** to higher levels, as shown in Figure 20.

It is also possible to optimize this hierarchy for transport of non-SDH/SONET formats. An example of how this can be implemented is shown in Figure 21, where a 1Gbps Ethernet signal is mapped into a C-5-2c which represents a STM-8. This principle can be extended to other non-SONET/SDH rates as currently defined.